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16. Abstract

First Environment developed this report under the guidance of New Jersey Transit to determine the potential risks of weather related events and impacts on its stationary assets. This research includes a survey of current reports and research on the topic; identifies and maps specific impacts to New Jersey Transit assets - commuter rail, light rail and bus; compiles national and international agency efforts underway regarding Transit strategies to protect assets; determines appropriate resilience strategies for the impacts identified; provides a summary level costs and benefits for each of the resilience strategies identified; and summarizes and highlights cost effective strategies to maintain NJ TRANSIT current and planned future services. This report provides a regional overview and can be used to identify critical impacts on assets and take appropriate measures to reduce its vulnerability to extreme weather.

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Resilience of NJ TRANSIT Assets to Climate Impacts

Final Report
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DISCLAIMER STATEMENT

First Environment performed the research work in a professional manner using that degree of skill and care exercised for similar projects under similar conditions by reputable and competent environmental consultants. First Environment cannot predict future changes in statutes or regulations that impact this research and therefore this research is valid as of the date of this report only. This research was conducted solely for the benefit of this client.

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EXECUTIVE SUMMARY

First Environment developed this report under the guidance of New Jersey Transit to determine the potential risks of weather related events and impacts on its stationary assets. This research includes a survey of current reports and research on the topic; identifies and maps specific impacts to New Jersey Transit assets - commuter rail, light rail and bus; compiles national and international agency efforts underway regarding Transit strategies to protect assets; determines appropriate resilience strategies for the impacts identified; provides summary level costs and benefits for each of the resilience strategies identified; and summarizes and highlights cost effective strategies to maintain NJ TRANSIT current and planned future services. This report provides a regional overview and can be used to identify critical impacts on assets and take appropriate measures to reduce its vulnerability to extreme weather.

BACKGROUND

New Jersey Transit (NJ TRANSIT) awarded this study to First Environment in 2011 to assist NJ TRANSIT with a review of potential risks of its assets to climate impacts. Shortly after the project began, Hurricane Irene exemplified the need for NJ TRANSIT to plan for extreme weather events with respect to asset resilience. For example, flooding from Irene washed out railway lines and roadways, crippling areas of the State's mass transportation operation.

NJ TRANSIT – Trenton Transit Center-Hurricane Irene

According to NJ TRANSIT's request for proposals, recent studies have estimated potential significant changes to the geography and weather patterns of New Jersey due to global climate impacts. Specific impacts were highlighted by Dr. Anthony Broccoli of Rutgers at the NJ Department of Transportation (DOT) Sustainable Transportation meeting held in January 2009. For example, sea level rise with permanent inundation and stronger storm surge and nor'easters, as well as an accelerated hydrologic cycle including more intense rain events and drier soils were identified. These impacts will affect the public transit assets in the state. New Jersey signed the Global Warming Response Act into law on July 6, 2007, and although there are expectations of risk management efforts to reduce greenhouse gas emissions, there is still a need to identify and determine specific resilience strategies for critical NJ TRANSIT assets.

Objectives

The goal of this project is for First Environment to assist NJ TRANSIT in determining the potential vulnerability and risk, as well as projected climate impacts on NJ TRANSIT stationary assets that include rails, structures, and buildings – and to develop cost-effective resilience strategies so NJ TRANSIT can protect these assets from negative impacts in the future. NJ TRANSIT can also use this information to protect its rolling stock (trains, buses, etc.) from severe weather. The assessment activities in this study provide information for NJ TRANSIT leadership to facilitate planning over the five, ten, and twenty - year horizons. First Environment also examined the fifty year planning horizon because the impacts of extreme weather continue to increase exponentially beyond the twenty year period.

In this phase, we systematically reviewed all stationary assets in their entirety and provide viable strategies for NJ TRANSIT to consider in developing capital and operating budget actions to avoid current and future risks and impacts. This report can then be used by NJ TRANSIT as a screening tool to perform a more detailed review or a criticality analysis of each specific asset (rails, structures and buildings) most at risk. This assessment provides NJ TRANSIT with indicators of risk so that NJ TRANSIT can prioritize the criticality of its at-risk assets.

Research Approach

First Environment's approach to this study included:

1. Literature review to identify potential climate impacts
2. Identification of climate impacts on classes of assets
3. Mapping of assets potentially at risk
4. Identification of indicators to assess severity of impacts on assets for the planning horizon
5. Identification of resilience strategies
6. Identification of estimates of costs to implement resilience strategies on a per unit basis to assist NJ TRANSIT in the planning process

First Environment performed a Literature Review of peer reviewed articles and documents relevant to this study starting with those identified by NJ TRANSIT.

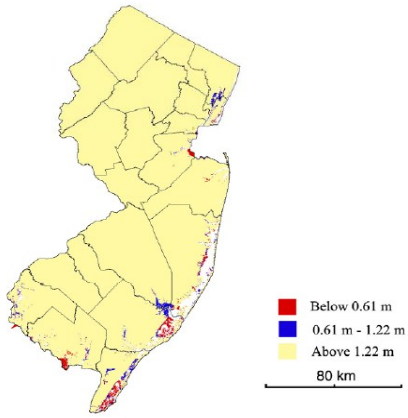
SUMMARY OF THE LITERATURE REVIEW

First Environment researched and incorporated a vast array of relevant information from international, US federal government, and regional studies. These studies identify the current and future impacts of weather on global, regional and transportation assets and provided sources for resilience strategies to prepare for and avoid those impacts.

The most recent study by the Federal Transit Administration (FTA), "Flooded Bus Barns and Buckled Rails: Public Transportation and Climate Change Adaptation FTA Report No. 0001," confirms and identifies the current impacts of climate change on transit assets nationally and projects out the impacts expected by the end of the century. The information in this study is consistent with other recent studies issued by United States Department of Transportation (USDOT), Federal Highway Administration (FHWA), New York City Panel on Climate Change (NPCC), and the Intergovernmental Panel on Climate Change (IPCC) which all generally project out impacts 80 years from now.

NJ TRANSIT is already experiencing many of the climate impacts (flooding, excessive heat, larger storms) that are expected to occur in the Northeast over the next 20 years. All of the literature we reviewed consistently reported that these patterns are expected to continue and become more frequent and intense over time. The longer term projections beyond the timeframe within this study indicate that up to 3 percent of New

Jersey land mass could be at risk as shown below.[1] As NJ TRANSIT maintains and builds for future assets to support operations, it must consider vulnerable areas.



Estimated coastal land area susceptible to permanent inundation applying sea level rise projections of 0.61 (24.0 in) and 1.22 m (48.0 in) in New Jersey

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level.
– IPCC AR4, 2007

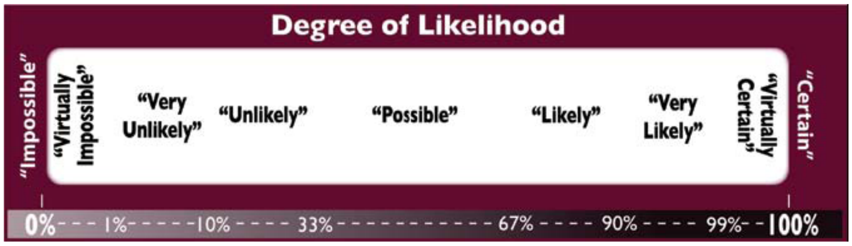
Lessons Learned

All the major transportation studies reference the IPCC's studies from 2000 and 2007. In 2000, the IPCC issued the Special Report Emissions Scenarios (SRES)[2] identifying the likelihood of changes in climate based on four possible scenarios. It assessed scientific, technical and socio-economic information regarding the risk of anthropogenic climate change. In 2007, the IPCC issued the Fourth Assessment Report (AR4) Synthesis[3] that provided evidence for environmental and climatic changes on a global level and incorporated a wide range of scientific perspectives. This report integrated both policy and science for the benefit of policymakers and planners to make comprehensive decisions.

[1] M.J.P. Cooper, M.D. Beevers, M. Oppenheimer. Future Sea Level Rise and the New Jersey Coast: Assessing Potential Impacts and Opportunities. Science, Technology and Environmental Policy Program, Woodrow Wilson School of Public and International Affairs, Princeton University, June, 2005
[2] IPCC Working Group III, IPCC Special Report: Emission Scenario. Intergovernmental Panel on Climate Change: Summary for Policymakers, 2000.

[3] Core Writing Team, R.K. Pachauri and A. Reisinger (Eds.) IPCC Fourth Assessment Report: Climate Change 2007. IPCC, Geneva, Switzerland. pp. 104

Using the language from the IPCC reports, a number of the international and national reports reviewed for this study use the definitions developed by the IPCC when forecasting climate impacts. The range of likelihood is as follows:



The data produced and published by the IPCC was then regionalized by different groups of researchers in an effort to illustrate specific impacts of climatic and environmental changes.

The Union of Concerned Scientists[4] in partnership with ATMOS Research & Consulting and Texas Tech University[5] focused on risks of increased temperature to the Northeast region and used the IPCC's emissions model as a basis to develop climate models specific to this region. Of particular significance to NJ TRANSIT is the increased temperature model they developed because NJ TRANSIT experiences operational impacts when the temperature exceeds 90 degrees Fahrenheit. First Environment was able to use this data to develop an Indicator of Risk for NJ TRANSIT.
Building on this regional approach, NASA and Columbia University worked with the New York City Panel on Climate Change to provide an integrated assessment for effective climate impact resilience in New York State. This report, prepared in 2009, has geographic and operational relevance for NJ TRANSIT as it provides a technical assessment of the range of climate impact hazards and its assets. Geographically, the climate impacts are similar to NJ TRANSIT and it is further relevant because NJ TRANSIT rail and bus transportation operations go into New York State.

[4] Union of Concerned Scientists, in partnership with ATMOS Research & Consulting and Texas Tech University "Northeast Climate Data": northeastclimatedata.org., 2005.

[5] P.C. Frumhoff, J.J. McCarthy, J.M. Melillo, S.C. Moser, D.J. Wuebbles. Confronting Climate Change in the US Northeast: Science, Impacts, and Solutions. Synthesis report of the Northeast Climate Impacts Assessment, Cambridge, MA: Union of Concerned Scientists (UCS), July, 2007

The USDOT FHWA Gulf Coast Study furthered the regional effort to address climate change and the need for adapting assets for extreme weather events. The Gulf Coast was chosen because of its strategic importance as a transportation hub for shipping and commerce. It focused on climate related impacts and provided greenhouse gas (GHG) risk management strategies, climate impact preparation and resilience strategies. This study was the first to look at entire transportation systems and developed a model for "regional decision makers to understand potential impacts on specific critical components of infrastructure and to evaluate adaptation options." [6]

Upon completion, USDOT/FHWA granted five additional pilot programs to test the model developed in the "Gulf Coast Study" to assess criticality of specific assets. The five pilots were: North Jersey Transportation Planning Authority (NJTPA), Oahu Metropolitan Planning Organization (MPO), San Francisco/ Metropolitan Transportation Commission (MTC), Washington State/DOT, Virginia State DOT/Hampton Roads. The conceptual models' goal is to help transportation organizations prioritize their assets so they can determine which are most critical and to reduce those assets from risk. The webinars for these case studies are all available to the public.[7] The five pilot studies identified that there is no single correct way to assess criticality in an overall vulnerability assessment.

For example, Washington State DOT examined roadways and facilities. They asked workshop participants (staff) to assist in identifying which roads/bridges, etc. were most vulnerable.

The NJTPA used the FHWA's conceptual model to conduct a climate change vulnerability analysis and risk assessment of the region's transportation assets. It is focused on specific geographic areas along the Northeast Corridor, along the Delaware River, and along the New Jersey coast. The criticality of assets identified ranged from roadways and bridges to passenger and freight rails. The study areas focused on impacts such as sea level rise, storm surge impacts and temperature. The NJTPA plans to take the findings of this report and present it to state agencies as part of an effort to educate state officials and agencies as to the vulnerabilities and recommended actions to reduce the potential risk to service, facilities and equipment.

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[6] Gulf Coast Study, Phase II Impacts of Climate Change and Variability on Transportation Systems & Infrastructure. U.S. Department of Transportation Federal Highway Administration. 53rd Annual Transportation Conference, February 23, 2010.

[7] http://www.fhwa.dot.gov/hep/climate/pilots.htm

Of major importance, in 2011, the Federal Transit Administration reported on impacts and resilience to the transportation sector on a national level through the study of recently increasing severe storms, high temperatures and flooding. The FTA issued the report, “Flooded Bus Barns and Buckled Rails: Public Transportation and Climate Change Adaptation, FTA Report No. 0001”, that captures the most up to date information on impacts of resilience strategies for transit systems.

The report states, “Climate change adaptation is essentially responsible risk management. It involves planning for system preservation and safe operation under current and projected conditions, recognizing that **hazard mitigation** [adaption] costs less than the damage from inaction. Adapting to climate change impacts will require interdisciplinary efforts among engineers, planners, frontline maintenance and operation staff, strategic planners, emergency response experts, and others. It is a long-term effort that will require not so much doing entirely different things, but doing some of the same things in a different way.”

The study also identifies factors for success. These include outside efforts such as those at the federal and state level to champion the effort and the embedding of climate impacts into existing work streams. This issue affects all parts of the organization and has the potential to affect the state of good repair of any asset if not properly managed. It also says climate change risk assessment has a high degree of uncertainty and is in flux. The climate is, by nature, changing; therefore it is necessary to continually revisit the effects of climate impacts, the criticality of assets and the agency’s preparedness (plan, do, check, adjust).

FTA studies on resilience help transit agencies understand how changes in the climate will impact transit assets. These impacts include:

- Increased temperature
- Sea level rise
- Higher storm surge
- Storm intensity and frequency
- Higher wind velocities
- Increased rain frequency and rainfall per event
- Increased flooding frequency and levels
- Increased lightening

- Increased snow levels per event
- More frequent icing events

As of late, the model predictions have been able to better narrow their focus on more local geographical segments of the globe, such as the northeast United States.[8] Depending on the projected outcome, this information is being used by transportation decision makers to assess the vulnerability of their assets.[9]

Although there is uncertainty regarding the timing, frequency, magnitude and locations of these extreme weather events and environmental changes, recent weather events are consistent with observed climate trends of being more severe. Some recent weather events include the following:[10]

- Vicksburg, MS (2011) – River flooding from heavy rains interrupted service.
- New York (2010) – Heavy snow stranded buses.
- New York (2007) – Heavy rain disrupted major segments of subway system affecting millions of commuters.
- Nashville, TN (2010) – Bus lots, maintenance and administrative facilities were flooded.
- New Jersey and Los Angeles, CA – Heat waves sagged catenary lines disrupting service.
- Washington, D.C. and Boston, MA – Heat waves caused rail kinks causing service disruptions requiring replacement of rail segments.
- Portland, OR – Heat waves caused electronic control equipment and fare box machines to overheat.
- Gulf Coast (2005) – Hurricane Katrina storm surge devastated transit agencies.

Based on the severity of these recent events, the transit industry has begun to assess their vulnerability and/or the criticality of their assets and take action to prepare and avoid the potential impacts related to these extreme weather events.[11]

[8] 5 Ibid
[9] T. Hodges, "Flooded Bus Barns and Buckled Rails: Public Transportation and Climate Change Adaptation, FTA Report No. 0001", World Transit Research, Federal Transit Administration, 2011.
[10] 9 Ibid
[11] 9 Ibid

SUMMARY OF THE WORK PERFORMED

The results of this study are condensed in Appendix 1. Appendix 1 shows by asset category the climate impact, effect on the asset, the specific assets at risk, the planning horizons for 5, 10, 20 and 50 years, the short term operational result, potential resilience strategies, and resilience implementation cost estimates by unit. To show the magnitude that extreme weather events will have on NJ TRANSIT assets, First Environment developed Indicators of Risk to quantify the expected increase in these events over NJ TRANSIT's planning horizons using scientifically accepted models from the literature review.

Identification of Climate Impacts on Classes of Assets

This study identifies the climate impacts by asset category, which includes Rails, Structures and Buildings. It also includes an in depth investigation into current weather related impacts experienced by NJ TRANSIT and what NJ TRANSIT is expected to experience based on information provided by NJ TRANSIT support documents and the literature review.

Prior to the beginning of the study, NJ TRANSIT provided a list of its assets with weather related impacts for the study. The examples streamlined the approach to properly focus on assets that are prone to weather related impacts. The identification of these assets allowed for maps and projection charts to illustrate directly the climatic impacts and where resilience strategies would be needed. The asset categories include:

- ***Rails (Heavy and Light Rail)***

- ***Structures (bridges, tunnels, culverts, and retaining walls)***

- ***Buildings (offices, terminals, stations and platforms, depots, and cabins)***

Bridgewater Station

Hoboken Station – Tickets & Information – Hurricane Irene

This study includes all rail lines where NJ TRANSIT operates service in New Jersey. NJ TRANSIT also owns assets outside of New Jersey, such as in the train yards in Suffern, New York and Morrisville, Pennsylvania near the Trenton Transit Station; and uses Amtrak's tunnel into Pennsylvania Station and Sunnyside Yards in Queens, New York. NJ TRANSIT relies on all of these assets to provide service, although they are not all owned by the agency. This emphasizes the need for NJ TRANSIT to coordinate its efforts with other transit agencies and freight railroads, such as Amtrak, Port Authority of New York and New Jersey (PANYNJ), Metro North, and Conrail.

From our literature review it is expected that climate impacts on NJ TRANSIT's assets over the next five, ten, and twenty year time periods will include:

- Increased temperature
- Sea level rise and higher storm surge
- Storm intensity and frequency that involve:
    - Higher wind velocities
    - Increased rain and rainfall per event
    - Increased lightning
    - Increased snow levels per event
    - More frequent icing events
    - Increased flooding frequency and levels

NJ TRANSIT is already experiencing these impacts and is already seeing which assets are at risk. NJ TRANSIT provided results from Hurricane Irene that descended upon New Jersey in August 2011. At the point of impact, Hurricane Irene had weakened to a Category 1 storm, nevertheless causing extensive damage to NJ TRANSIT assets. Some of the assets took weeks to restore to normal service, requiring not only an increase in labor but high financial investment. The cost to clean up and repair assets from Hurricane Irene was between $2 and $3 million – excluding the loss in revenue.

The number of these extreme weather events is expected to increase over the next twenty years and will have an even greater impact in the twenty to fifty year time frame. For this reason the fifty year planning horizon was prepared to propose future risk management efforts for NJ TRANSIT.

The study then identified the specific effects on the asset categories for each climate impact as shown in Appendix 1. Each specific asset was considered in this process and all associated weather related impacts were acknowledged based on asset location. NJ TRANSIT and FTA documentation supported the issues that are currently being faced in relation to this matter. The study then builds on and projects the potential frequency of these recurring problems.

For example, increased temperature (the number of days over 90 degrees Fahrenheit) for the category of rails will likely result in thermal expansion and buckling of the rails; the heat will also damage electrical equipment (switches, gates, signals), increase potential for sagging and snapping of catenary lines, and increase the opportunity for widespread electric utility brownouts and outages associated with grid damage.

Rail Buckled from High Heat[12] - Photo Courtesy of USDOT Volpe Center

Sea level rise is already having an impact on higher storm surges. Higher storm surge results in bridge inaccessibility (during high tide), increase scouring of retaining walls and bridges, culvert blockages/system back-ups, and damage to structures from salt water corrosion.

Sea level rise, however, is not expected to pose an immediate threat for NJ TRANSIT within the next 20 years. While sea levels are expected to rise slightly, they are not expected to accelerate enough to have an impact within this planning horizon. In the 50 year time frame, sea level rise will result in specific facilities such as rail right of ways, and other systems or components becoming increasingly vulnerable to temporary or permanent flooding. Inundation of certain areas as a result of future sea level rise also poses a threat.

Storm intensity and frequency can have a cumulative impact on all NJ TRANSIT's assets. For example, higher wind velocities result in debris damaged buildings, terminals, platforms, stations, and cabins. Increased rain frequency and rainfall per event can result in inadequate culvert capacity. Increased snow levels and more frequent icing events can result in inaccessible stations, platforms, depots, buildings, and maintenance garages, as well as additional damage to catenary lines, switches and

[12] T. Hodges, "Flooded Bus Barns and Buckled Rails: Public Transportation and Climate Change Adaptation, FTA Report No. 0001", World Transit Research, Federal Transit Administration, 2011.

gates. Increased lightning can damage electrical equipment, such as switches, gates, and signals.

As seen during Hurricane Irene, increased flooding can affect every asset category and can cripple specific segments of service for NJ TRANSIT. This Category 1 Hurricane resulted in heavy rains, which washed away the rail bed and rails, damaged structures, and made bus parking areas such as the Oradell Garage inaccessible.

Short-term Operations

This study identifies current operational outcomes associated with assets and climate impacts (Appendix 1). In general, vulnerable assets interrupt, slow, or result in substitute service that NJ TRANSIT passengers are already experiencing. Climate impacts affect customer satisfaction and all other key performance indicators.

To safeguard vital assets, Bus Operations moved flood-prone Oradell Depot buses to Paramus Park Mall and then again to Garden State Plaza as the water rose at Paramus Park.

Substitute service for interrupted rail

NJ TRANSIT key performance metrics include:

- Safety and Security;
- Customer Experience;
- Corporate Accountability;
- Financial Performance; and
- Employee Engagement.

NJ TRANSIT currently tracks customer satisfaction on the Scorecard Initiative that was launched in the summer of 2011 as a way for the organization to track and share with the public its performance on key metrics. Customers of NJ TRANSIT buses, rail, light rail, and Access Link participate in a quarterly survey that rates their satisfaction on a scale of 0 to 10. In addition to an overall score, customers rate individual service indicators such as on-time performance, condition of the station, and availability of information.

The RiverLINE Scorecard demonstrates the effect of service disruption on customer satisfaction. As a result of Hurricane Irene and the amount of rainfall, a section of embankment (280 feet) between the Roebling and Bordertown Stations failed and partially collapsed onto the NJ TRANSIT RiverLINE tracks and Right of Way. The failure caused a massive loss of slope and the embankment was left in an unstable condition. Following the initial collapse, the embankment continued to exhibit sustained failure with additional movements toward the track and the Right of Way. This ultimately caused the siding track to be taken out of service until further notice and required a speed restriction that made it impossible to maintain peak period weekday operations. NJ TRANSIT implemented a temporary less frequent schedule. The Scorecard results demonstrated a decrease in customer satisfaction. Overall satisfaction with scheduling dropped from 7.6 in the previous quarter to 4.7 largely as a result of dissatisfaction with peak scheduling. Satisfaction with the handling of service disruptions also dropped from 5.8 to 4.6.

Loss of the embankment along the RiverLINE – Hurricane Irene

The affected area had to be immediately stabilized to prevent catastrophic failure. It required an emergency contract to be awarded that included investigation, testing, recommendations, design, and construction.


Temporary protection – post Hurricane Irene

Mapping

Research information enabled the preparation of flood, coastal vulnerability, and forestation maps for NJ TRANSIT using GIS data. The maps (Appendix 2, Maps 1-9) are reflective of the most recent information readily available from Federal Emergency Management Agency (FEMA), US Geological Survey (USGS), and NJDEP, and are consistent with the findings in NJTPA's criticality study. They provide a basis for NJ TRANSIT to identify and prioritize individual assets affected by the change in climate.

Flood Hazard Area

Flood Hazard Area maps were generated using Q3 Flood data from FEMA (1996). These maps display Rail Line corridors and Bus assets in relation to the 1 percent chance flood, which is called the 100-year flood; and the 0.2 percent chance flood, the 500-year flood. These maps include:

- Map 1: New Jersey Transit Northern Jersey Bus Assets, Flood Hazard Areas
- Map 2: New Jersey Transit Southern Jersey Bus Assets, Flood Hazard Areas
- Map 3: New Jersey Transit Northern Jersey Light Rail Lines, Flood Hazard Areas
- Map 4: New Jersey Transit Southern Jersey Light Rail Lines, Flood Hazard Areas
- Map 5: New Jersey Transit Northern Jersey Rail Lines, Flood Hazard Areas
- Map 6: New Jersey Transit Southern Jersey Rail Lines, Flood Hazard Areas

Northeast Corridor Flooding from Hurricane Irene

Coastal Vulnerability and Storm Surge

The Coastal Vulnerability and Storm Surge map (Map 7) was generated using Storm Surge data from NJDEP Bureau of Tidelands Management (1996), and Coastal Vulnerability to Sea-Level Rise data from the USGS, Woods Hole Field Center (2001). The Coastal Vulnerability to Sea-Level Rise data looks at relative potential for coastal change due to the future sea level rise based on variables including geomorphology, regional coastal slope, tide range, wave height, relative sea-level rise and shoreline erosion and accretion rates. Storm Surge data represents natural waterways now or formerly tide-flowed at mean high water. Map 7 displays Rail Line corridors and Bus assets in relation to these known areas of flooding or potential flooding.

- Map 7: New Jersey Transit Rail Lines, Coastal Vulnerability and Storm Surge Areas

North Jersey Coast Line-track bed undermined as a result of Hurricane Irene

Forested Areas

The Forested Area maps were generated using Land Use/Land Cover data from the NJDEP Information Resources Management Bureau of Geographic Information Systems (2010). These maps identify the geographical areas within 50 feet of the Rail Line corridors and Catenary lines that have heavy and medium forestation levels. These maps include:

- Map 8: New Jersey Transit Catenary Rail Lines, Forested Areas
- Map 9: New Jersey Transit All Commuter Rail Lines, Forested Areas

Morris and Essex Lines-Hurricane Irene

Statistical Models

This report reviewed and developed statistical models for the 5, 10, and 20 year planning horizons to determine results specific to NJ TRANSIT. In recent years, NJ TRANSIT has already been experiencing more extreme weather; the models indicate these increases. To date, higher heat events, more intense rainfall events and storm intensity issues have all disrupted service and presented significant financial problems for NJ TRANSIT. Although sea level rise impacts have not been affecting current NJ TRANSIT assets to date, there is an indication that there will be a significant problem within the 20 – 50 year range.

As stated in the literature review, the models project climate through this century based on different expectations of carbon emissions. The variance in the models do not demonstrate a large difference within the next 20 years (NJ TRANSIT's planning horizon); however, in 50 years there is a surge in temperature, sea level rise, and flooding.

Hoboken Terminal and Yard sits directly on the Hudson River

Indicators of Risk

As there are no short-term (5-20 year climate) models available to predict NJ TRANSIT's extreme weather events, First Environment has developed Indicators of Risk that quantify, on average, the increase in extreme weather events that will affect NJ TRANSIT over the next twenty years and beyond. These Indicators identify the scale of the risk associated with these impacts. They include Days Over 90 Degrees Fahrenheit, Sea Level Rise, and Storm/Flood Frequency.

<u>Days Over 90 Indicator</u>

Days over 90 degrees Fahrenheit are problematic for NJ TRANSIT. To demonstrate the magnitude of increased heat events and increased frequency for NJ TRANSIT, First Environment used annual projection data from the Union of Concerned Scientists, in partnership with ATMOS Research and Consulting and Texas Tech University. First Environment took the annual projection data and prepared an average number of days over 90 degrees Fahrenheit for each planning horizon and emission scenario that was based on the IPCC emissions scenarios. The data was trended to supply a percentage increase for each horizon timeframe. A table was also formulated with each data point, fitted with a polynomial trend line and coefficient of determination calculation.

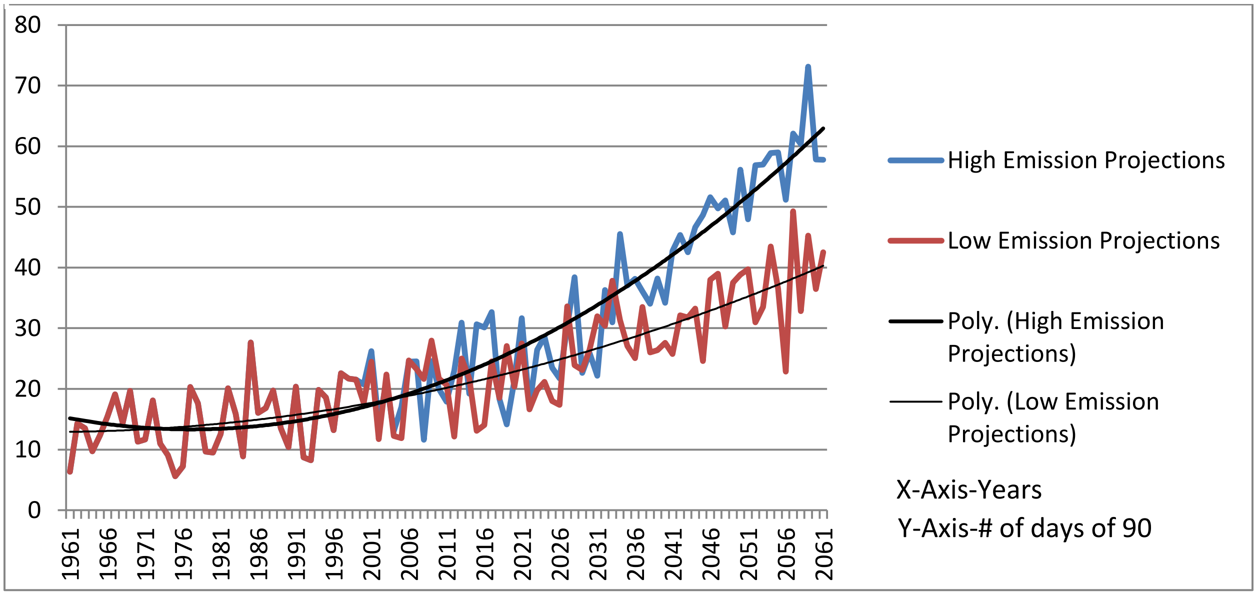

Figure 1. Days over 90 Degrees Fahrenheit Indicator

Table 1 - Days over 90 Degrees Fahrenheit Indicator

Years	Baseline Ave.	Increase in days over 90 – Trend High Emissions	Increase in days over 90 - Trend Low Emissions	% change Trend – High Emissions	% change Trend Low Emissions
1980-1999	16.3				
2012-2016		26	22	57%	37%
2017- 2021		28	24	74%	45%
2022- 2031		33	26	100%	58%
2032- 2061		47	32	187%	95%

Sea Level Rise

Data was available for projections of sea level rise from the IPCC and Stefan Rahmstrof. Based on this data, sea level will have minimal effects on the assets within the 5, 10 and 20 year planning horizons; however, sea level rise will have crippling effects on assets beyond the 50 year planning horizon.

The IPCC and Rahmstrof used 1990 as their base to project future sea level rise. These ranges again were formatted using the planning horizons applicable to NJ TRANSIT and fit to a statistical curve with a polynomial best fit line.

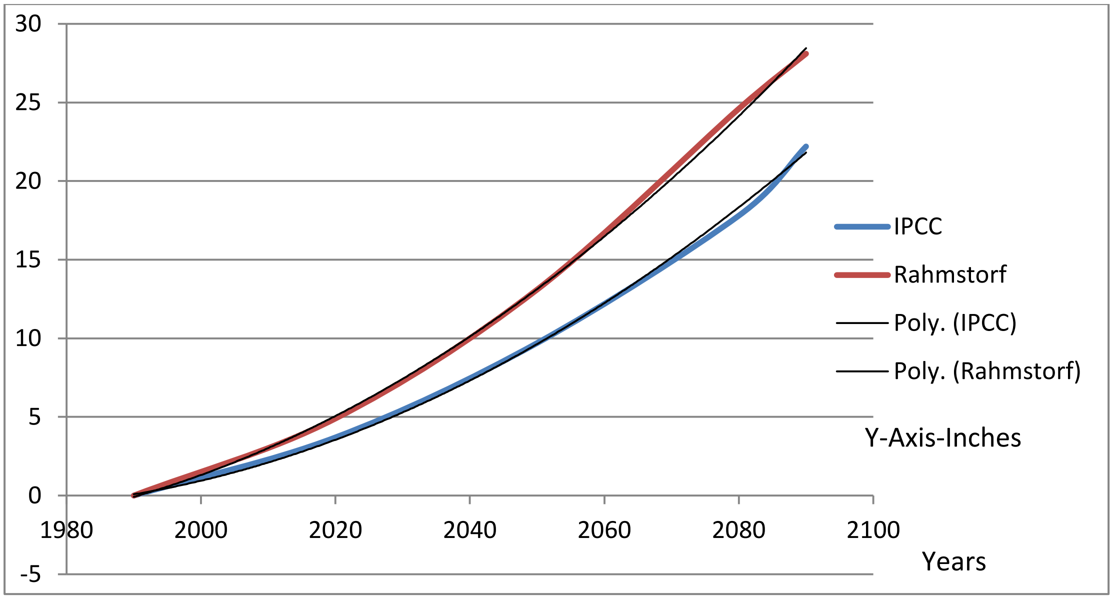

Figure 2. Seal level rise in inches

Table 2 - Sea level rise in inches

Sea Level Rise in inches over 1990 base year	**Range in inches during period - IPCC**	**Range in inches during period-Rahmstorf**
2012-2016	2.4-3	3.4-4.2
2017-2021	3.1-3.7	4.4-5-3
2022-2031	3.9-5.5	5.5-7.7
2032-2061	5.7-12.5	7.9-16.8

Storm/Flood Frequency

As there is no clear storm intensity data available for NJ TRANSIT's planning horizon, First Environment used flood data from the NYPCC study to develop an indicator of storm intensity. Using flood data, the results show both an increase in frequency and intensity of storms over the next 20 years and beyond.

The charts and table produced from this data illustrate an increase in flood and storm frequency. For example, the "100 year storm" will happen approximately every eighty years. This will affect assets not only in areas along the NJ Coast line but in all flood zones within the state. As stated previously, the increases in flooding and storms will present significant impacts to NJ TRANSIT assets. The recurring problems associated with these indicators will have considerable effects on labor and material costs, as well as operational difficulties.

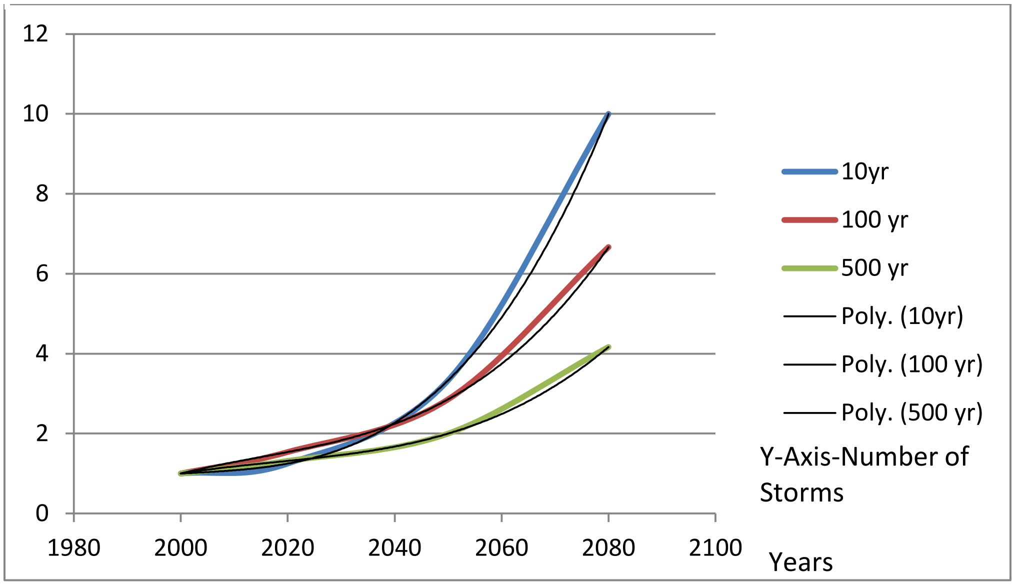

Figure 3. Storm/flood frequency

Table 3 - Average Percent Increase in Flooding Frequency

	Average % Increase in Frequency over Year 2000		
	10 Year Flood	100 Year Flood	500 Year Flood
2012-2016	13%	39%	23%
2017-2021	23%	51%	30%
2022-2031	47%	72%	41%
2032-2061	209%	171%	93%

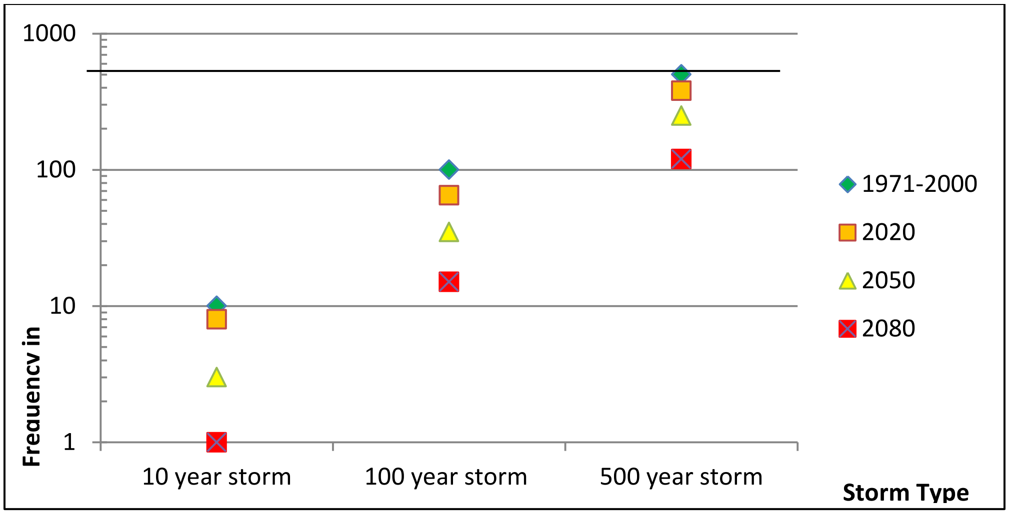

Figure 4. Frequency of intense storms

Potential Resilience Strategies

Based upon the projected long-term climate impacts, First Environment and our subcontractor, Dewberry Engineers, Inc. (Dewberry), determined potential risk management strategies to address each of the predicted potential impacts. The purpose of implementing a resilience strategy is to make the specific assets more resilient to a particular impact. The level of resilience identified in the study was intended to minimize operational impacts to NJ TRANSIT operations after an extreme storm event, increased flooding or increase in high temperature days.

Risk management strategies have been identified based upon information presented in the literature review with particular emphasis on FTA's "Flooded Bus Barns and Buckled Rails" (August 2011) report and NJ TRANSIT operational experience related to the research team. Since the current literature in this area, particularly related to potential cost impacts, was not robust, the research team utilized their existing knowledge of NJ TRANSIT design standards and operations in the development of the risk management strategies. Risk management strategies have been developed using NJ TRANSIT's current design standards and operations as the baseline scenario. It is assumed that impacts may be slightly mitigated in future years independent of the specific resilience strategies as NJ TRANSIT design specification change to address future revisions in building codes and regulations to which NJ TRANSIT is subject. Manufacturers' literature and representatives were also contacted to discuss potential risk management techniques. These strategies are generally associated with their experience with similar rail assets in other climates.

Estimated Costs to Avoid Service Disruptions

For each risk management strategy identified, Dewberry developed a cost range for implementation adjusted to the current base year (2012). The costing was developed using a high to low to represent cost variability throughout the state as well as implementation of a range of risk management options for specific assets. For example, the low range for potential increase in tunnel ventilation assumes the need to add two (2) additional ventilation shafts while the high end assumes six (6) additional shafts. In this manner, the mean of this range provides a "typical" cost impact for the range of NJ TRANSIT assets. In general, Dewberry developed costs based upon information in the following materials:

- Cost impact data presented in literature reviews
- RS Means Cost Works database using 2012 Q1 cost information provided (Newark and Vineland were used to provide costing ranges throughout the state.)
- Manufacturer cost information
- Historic cost data provided by NJ TRANSIT

Cost estimates have been provided on a unit basis (i.e. $/mile of track) and are budgetary in nature based upon a typical NJ TRANSIT facility. Dewberry and First Environment were required to make certain assumptions in order to generate these order of magnitude costs which are detailed in the tables in Appendix 1. Costing data obtained from literature reviews have been adjusted for New Jersey process per indices presented in the RS Means Cost Works database. Specific engineering studies would be required to estimate costs for a particular asset. Because the impacts associated with climate impact on transportation assets is an emerging field, it is expected that the body of knowledge in this area will increase substantially in the next few years as additional studies are undertaken.

CONCLUSION AND RECOMMENDATIONS

In conclusion, NJ TRANSIT has already been experiencing and will continue to experience weather related impacts. NJ TRANSIT can expect more frequent service disruptions over the next 20 years and must consider how the weather is affecting the state of good repair for its assets. The next immediate step for NJ TRANSIT is to prioritize its critical assets and determine which resilience strategies it wants to implement. This report provides a regional overview and can be used as a screening tool for NJ TRANSIT to identify its specific critical assets and take appropriate measures to reduce its vulnerability to extreme weather.

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Appendix 1. Climate Impacts on Classes of Assets: Summary Tables

Climate Impacts on Buildings: Summary Table

Buildings include stations, depots, platforms, cabins (Does this also include Park and Ride lots, maintenance yards, and fueling stations?)

ASSET CATEGORY	Climate Impact	Effect on Buildings	Assets at Risk	Planning Horizon Timeframe (yrs) 1 to 5	6 to 10	11 to 20	20-50	Short-term Operational Impacts	Potential Asset Management Strategies	Implementation Cost Estimates per Unit Low	High
Buildings	1. Increased Temperature	Electric utility brownouts and outages associated with grid demand	All Stations and Office Buildings on grid	X	X	X	X	Cancelled service	Install emergency generators or have supplemental power feeds.	NJ Transit coordination with PJM to increase electric service reliability. May result in additional cost directly but most likely a utility cost.	
		Inadequate Platform Shelter	All Platforms	X	X	X	X	N/A	Install high temperature shade shelters at platforms	$10,000 each	$50,000 each
		Inadequate ventilation systems	Maintenance Garages, Depots and Yards	X	X	X	x	Modified work schedules	Increase ventilation in building	$300,000	$2,000,000
		HVAC systems inadequately sized	All Stations and Offices	X	X	X	X	N/A	Upgrade or replace existing systems	$125,000	$300,000
	2. Sea Level Rise	Buildings are no longer above sea level	NJ coastal zone, Delaware Bay, and Tidal Delaware River buildings				X	N/A	Seawall or replace / relocate asset	$5,000,000	$10,000,000
	2.1 Higher storm surge	Buildings destruction and degradation	NJ coastal zone, Delaware Bay, and Tidal Delaware River buildings	X	X	X	X	N/A	Repair or replace structure	$10,000	$10,000,000
	3. Storm Intensity and Frequency										
	3.1 Higher wind velocities	Debris damaged platforms, stations and cabins	Platforms, stations and cabins in wooded areas	X	X	X	X	Reduced and cancelled service	Roof / Window Replacement and/or Reinforcements	$10,000	$1,300,000
		Wind damaged buildings	All buildings and stored outdoor vehicle /equipment	X	X	X	X	Possible slowed service	Roof Replacement and/or Reinforcements	$10,000	$1,300,000

Design future buildings with construction materials and arrangements that reduce temperature (vegetated green roofs, reflective roof materials, etc.) More efficient AC units (SEER 14) typically require a 20% upcharge.

Consider building new structures outside of flood zones. Participate in current real estate acquisition for future relocation of a facility as an adaptation strategy.

Short Term Adaptations - Raise the current entry and egress levels. Provide temporary alternative facilities to store vehicles, equipment, etc. in advance of a storm surge.

Avoid storing outdoor vehicles or equipment near potential hazards (large trees, utility poles, etc).

Climate Impacts on Buildings: Summary Table

Buildings include stations, depots, platforms, cabins (**Does this also include Park and Ride lots, maintenance yards, and fueling stations?)**

ASSET CATEGORY	Climate Impact	Effect on Buildings	Assets at Risk	Planning Horizon Timeframe (yrs)				Short-term Operational Impacts	Potential Asset Management Strategies	Implementation Cost Estimates per Unit	
				1 to 5	6 to 10	11 to 20	20-50			Low	High
Buildings	*3.2 Increased rain frequency and rainfall per event*	N/A	N/A	X	X	X	X				
	3.3 increased lightning	Damage to rooftop or adjacent electrical equipment	All Stations and Depots	X	X	X	X	Possible Slowed Service	Verify electrical equipment, wiring, and associated facilities are protected	No cost besides equipment replacement anticipated	
	3.4 Increased snow levels per event	Inaccessible stations, platforms, depots, buildings and maintenance	All Stations and platforms	X	X	X	X	Cancelled or delayed service	Additional snow removal and Roof Replacement and/or Reinforcements	$10,000	$1,300,000
	3.5 more frequent icing events	Increased road salt corrosion of station platforms	All station platforms	X	X	X	X	N/A	Increased maintenance / cleaning and coating of exposed steel due to de-icing salt corrosion, concrete spall repair	$25,000 each	$100,000 each
		Inaccessible stations, platforms, depots, buildings and maintenance	All platforms	X	X	X	X	Cancelled or delayed service	Increased maintenance	Additional Maintenance	
	3.6 Increased flooding frequency and levels	Damage or destruction to building	Flood zone Buildings	X	X	X	X		Repair or replace structure	$10,000	$10,000,000
		Increased debris clogging station drainage	Flood zone Stations	X	X	X	X	Delayed or slowed service	Clean drainage systems and consider installing additional drainage	$10,000	$157,000

There may be a significant effect on buildings' drainage due to increased rainfall (insufficient gutters, roof ponding, etc). An alternative example would be to install vegetated rooftop gardens to absorb excess rainfall (and also provide a cooling effect for the interior of the building).

All existing structures will need to be analyzed to determine if they can support the additional snow dead loads.

Also, may want to consider that more frequent icing events will wear out / damage building gutter systems faster.

Some short term alternatives to mitigate flooding at and adjacent to buildings and stations would be to utilize pervious concrete pavements and install rain garden barriers for run-off.

Climate Impacts on Rails: Summary Table

Rails including rails, rail beds, rail drainage systems, catenary lines, electrical lines, switches and signals. Bridges, culverts, retaining walls and other structures are included under structures.

ASSET CATEGORY	Climate Impact	Effect on Rail System	Assets at Risk	Planning Horizon Timeframe (yrs)				Short-term Operational Impacts	Potential Asset Management Strategies	Implementation Cost Estimates per Unit	
				1 to 5	6 to 10	11 to 20	20-50			Low	High
Rails	1. Increased Temperature	Thermal expansion and buckling of rails. Warp and misalignment of tracks due to uneven thermal expansion (when shade cools adjacent sections)	All rails	X	X	X	X	Slowed service or watering of track	Installation of expansion joints/additional expansion joints in frequently buckled areas. Another possible remedy is the installation of anchors and ties to secure the track and prevent buckling.	$15,000 per mile.	$20,000 per mile.
		Sagging and snapping of catenary lines	Electrified catenary lines	X	X	X	X	Cancelled and substitute service (bus)	Setting higher rail neutral temperature in new rail lines.	Equip maintenance personnel with neutral temperature monitoring devices and perform periodic inspections (possible short-term adaptation). It is also important to not set the neutral rail temperature too high to the point where it becomes vulnerable to breaking during colder weather.	
		Damage to electrical equipment (switches, gates, signals)	All electrical equipment	X	X	X	X	Upgrade / replace current electrical equipment and install additional ventilation.	Revise specifications for equipment (such as transformers and signals) to withstand higher ambient temperatures	5% increase is electrical equipment costs.	
		Sagging and snapping of catenary lines	Electrified catenary lines	X	X	X	X	Cancelled and substitute service (bus)	Replacement of existing catenary line tensioners.	TBD	TBD
		Electric utility brownouts and outages associated with grid demand	All electrical equipment on grid	X	X	X	X	Slowed, cancelled and substitute service (bus)	Reduce electric demand of rail operations or provide supplemental power feeds.	NJ Transit coordination with PJM to increase electric service reliability. May result in additional cost directly but most likely a utility cost.	
	2. Sea Level Rise	Rail systems or components no longer above sea level	NJ coastal zone, Delaware Bay, and Tidal Delaware River assets				X	N/A	Replacement of existing track above sea level (if feasible or seawall).	$225,000 per mile	$1,800,000 per mile
	2.1 *Higher storm surge*	Rail and rail bed destruction	NJ coastal zone, Delaware Bay, and tidal Delaware River rail assets	X	X	X	X	Cancelled and substitute service (bus)	Repair rail, rail bed and embankments	$1,500,000 per event	$3,000,000 per event
		Flooded rails	NJ coastal zone, Delaware Bay, and tidal Delaware River rail assets	X	X	X	X	Cancelled and substitute service (bus)	Cancelled services	Costs included in debris cleanup and electric repair numbers.	
		Damage (corrosion) to electrical equipment (switches, gates, signals) due to contact with salt water	NJ coastal zone, Delaware Bay, and tidal Delaware River electrical equipment assets	X	X	X	X	Slowed service	Repair of electric equipment, wiring and associated facilities	$115,000 per event	$230,000 per event
		Debris on rails	NJ coastal zone, Delaware Bay, and Tidal Delaware River rail assets	X	X	X	X	Cancelled and substitute service (bus)	Cleanup of storm debris from rail tracks and right of way	$415,000 per event	$830,000 per event

Climate Impacts on Rails: Summary Table

Rails including rails, rail beds, rail drainage systems, catenary lines, electrical lines, switches and signals. Bridges, culverts, retaining walls and other structures are included under structures.

ASSET CATEGORY	Climate Impact	Effect on Rail System	Assets at Risk	Planning Horizon Timeframe (yrs)				Short-term Operational Impacts	Potential Asset Management Strategies	Implementation Cost Estimates per Unit	
				1 to 5	6 to 10	11 to 20	20-50			Low	High
Rails	3. Storm Intensity and Frequency										
	3.1 Higher wind velocities	Debris damaged electrical equipment (signals, switches, gates) & electrical lines	Forested areas electrical equipment and lines	X	X	X	X	Slowed service	Repair of electric equipment, wiring and associated facilities	$50,000 per event	$115,000 per event
		Debris damaged catenary lines	Forested areas catenary lines	X	X	X	X	Cancelled and substitute service (bus)	Repair of debris damaged catenary lines	$5,000 each	$20,000 each
		Debris blocked rails	Forested areas rail lines	X	X	X	X	Cancelled and substitute service (bus)	Cleanup of storm debris from rails tracks and right of way	$200,000 per event	$415,000 per event
		Inhibited transmission from catenary lines to electric traction system	All electric powered rail lines	X	X	X	X	Slowed service	Require design changes	Additional study required	Additional study required
	3.2 Increased rain frequency and rainfall per event	Increased subsidence/erosion of sub base and rail due to runoff	All rails	X	X	X	X	Cancelled and substitute service (bus)	Stabilization of soil embankments	$15,000 per mile	$75,000 per mile
		Increased leaf covered lubricated rails	Forested Areas	X	X	X	X		Additional Maintenance	Cost of wheel truing and other maintenance.	Cost of wheel truing and other maintenance.
		Overwhelmed drainage systems	All rail beds	X	X	X	X	Cancelled and substitute service (bus)	Building additional drainage to manage	$110,000 per mile	$185,000 per mile
	3.3 Increased lightning	Inhibited transmission from catenary lines to electric traction system	All electric powered rail lines	X	X	X	X	Slowed Service			
		Damage to electrical equipment (switches, gates, signals)	All electric powered equipment	X	X	X	X	Cancelled and substitute service (bus)	Repair of electric equipment, wiring and associated facilities	$75,000 per event	$150,000 per event
	3.4 Increased snow levels per event	Impassable rails	All rails	X	X	X	X	Cancelled and substitute service (bus)	Increased maintenance of snow removal	Cost of Additional Maintenance	
	3.5 More frequent icing events	Inhibited transmission from catenary lines to electric traction system	All electrified lines	X	X	X	X	Slowed service	Increase maintenance	Cost of maintenance to remove grease from line.	Cost of maintenance to remove grease from line.
		Snagged or snapped catenary lines	All electrified lines	X	X	X	X	Cancelled and substitute service (bus)	Repair damaged catenary lines	$5,000 each	$20,000 each
		Loss of traction on iced rails	All rails	X	X	X	X	Slowed service	Required additional maintenance and rail de-icers to minimize disruptions	Cost of Additional Maintenance	
		Damage to electrical equipment (switches, gates, signals)	All electric lines	X	X	X	X	Cancelled and substitute service (bus)	Repair of electric equipment, wiring and associated facilities	$115,000 per event	$230,000 per event
	3.6 Increased flooding frequency and levels	Rail and rail bed destruction	Flood zone rails	X	X	X	X	Cancelled and substitute service (bus)	Replacement of existing track above sea level.	$225,000 per mile	$250,000 per mile
		Damage to electrical equipment (switches, gates, signals)	Flood zone electrical equipment	X	X	X	X	Slowed service	Repair of electric equipment, wiring and associated facilities	$100,000 per event	$250,000 per event
		Debris on rails	Flood zone rails	X	X	X	X	Cancelled and substitute service (bus)	Cleanup of storm debris from rails tracks and right of way	$400,000 per event	$850,000 per event
		Flooded rails	Flood zone rails	X	X	X	X	Cancelled and substitute service (bus)	Replacement of existing track above sea level (if feasible or seawall).	$225,000 per mile	$1,800,000 per mile

A possible short term adaptation would be to upgrade the insulation and moisture prevention of the existing equipment vulnerable to water infiltration.

Tangential effects on maintenance, operational delays, and construction will be discussed qualitatively in report , but not included in financial analysis.

Climate Impacts on Structures: Summary Table

Structures include bridges, tunnels, culverts, retaining walls

ASSET CATEGORY	Climate Impact	Effect on Structures	Assets at Risk	Planning Horizon Timeframe (yrs)				Short-term Operational Impacts	Potential Asset Management Strategies	Implementation Cost Estimates per Unit		
				1 to 5	6 to 10	11 to 20	20-50			Low	High	
Structures		Inadequate ventilation systems	Tunnels	X	X	X	X	reduced and cancelled service	Increase tunnel ventilation	$200,000	$600,000	
	1. Increased Temperature	Thermal expansion, buckling, framing, supports of bridges and culverts	All Bridges and Culverts	X	X	X	X	reduced and cancelled service	Evaluate adequacy of structures and implement remedies as required.	$250,000	$2,000,000	One remedy may involve replacing the existing girder bearings with ones that allow for greater thermal expansions in all directions (multi-rotational bearings). This would require jacking the existing girders and replacing the existing bearings which may temporarily disrupt service.
	2. Sea Level Rise	Structures are no longer above sea level	NJ coastal zone, Delaware Bay, and Tidal Delaware River structures				X	N/A	Seawall or replace structure	$85,000	$20,000,000	
	2.1 Higher storm surge	Bridge inaccessibility (when combined with high tide)	NJ coastal zone, Delaware Bay, and Tidal Delaware River and bridges	X	X	X	X	reduced and cancelled service	Replace approach (or replace and raise structure?)	$500,000	$2,500,000	
		Increased scouring of retaining walls, abutments, and foundations	NJ coastal zone, Delaware Bay, and Tidal Delaware River retaining walls and bridges	X	X	X	X	reduced and cancelled service	Increased maintenance and scour mitigation measures	$180,000 each	$550,000 each	Remedies may involve installing scour control to protect the substructures (rip rap, sheet piles, gabion walls, soil cement, articulating grout filled mattresses, etc.) as well as periodic debris removal and re-grading to prevent contraction scour due to potential shifts in the waterway channel.
		Subsidence/Heave of retaining walls and bridge substructures	NJ coastal zone, Delaware Bay, and Tidal Delaware River retaining walls and bridges	X	X	X	X	reduced and cancelled service	Stabilization of soil embankments and hardening (strengthening?) of existing retaining walls	$15,000 per mile	$2,000,000 per mile	Remedies may involve underpinning foundations with micropiles, soil cement stabilization, and anchoring.
		Culvert blockages/system back ups	All drainage culverts	X	X	X	X	reduced service	Increased maintenance of system / increased replacement (and/or installing supplemental drainage?)	$1,000 each	$25,000 each	Increased cleaning and debris removal of culverts / drainage structures, channel re-grading adjacent to the upstream and downstream headwalls, and placement of rip rap (or other scour control measures) to prevent increased channel erosion. Replacement of culverts in poor condition and installation of supplemental drainage improvements where necessary.
		Tunnel Inaccessibility	All tunnels	X	X	X	X	reduced and cancelled service	Installation (or additional reinforcement) of pumps, barriers, gates, etc.			This may be an item for consideration due to the effects of a storm surge on the existing tunnels.
		Corrosive damage to structures due to salt water exposure	NJ coastal zone, Delaware Bay, and Tidal Delaware River retaining walls and bridges	X	X	X	X	reduced and cancelled service	Increased maintenance / cleaning and coating of structures / substructure concrete spall repairs	$180,000 each	$550,000 each	Blast (or spot) cleaning of superstructure (could be expensive depending on methods and containment requirements), miscellaneous steel repair or replacements (framing members, bolts / rivets, etc.), and salt water environment specified paint coating. Increased substructure concrete spall repairs will also be necessary due to the salt water corrosive effect on the reinforcing steel. As an alternative to cleaning and coating, application of rust conversion treatment products (such as Stop Rust) to corroded areas may be considered.

Climate Impacts on Structures: Summary Table

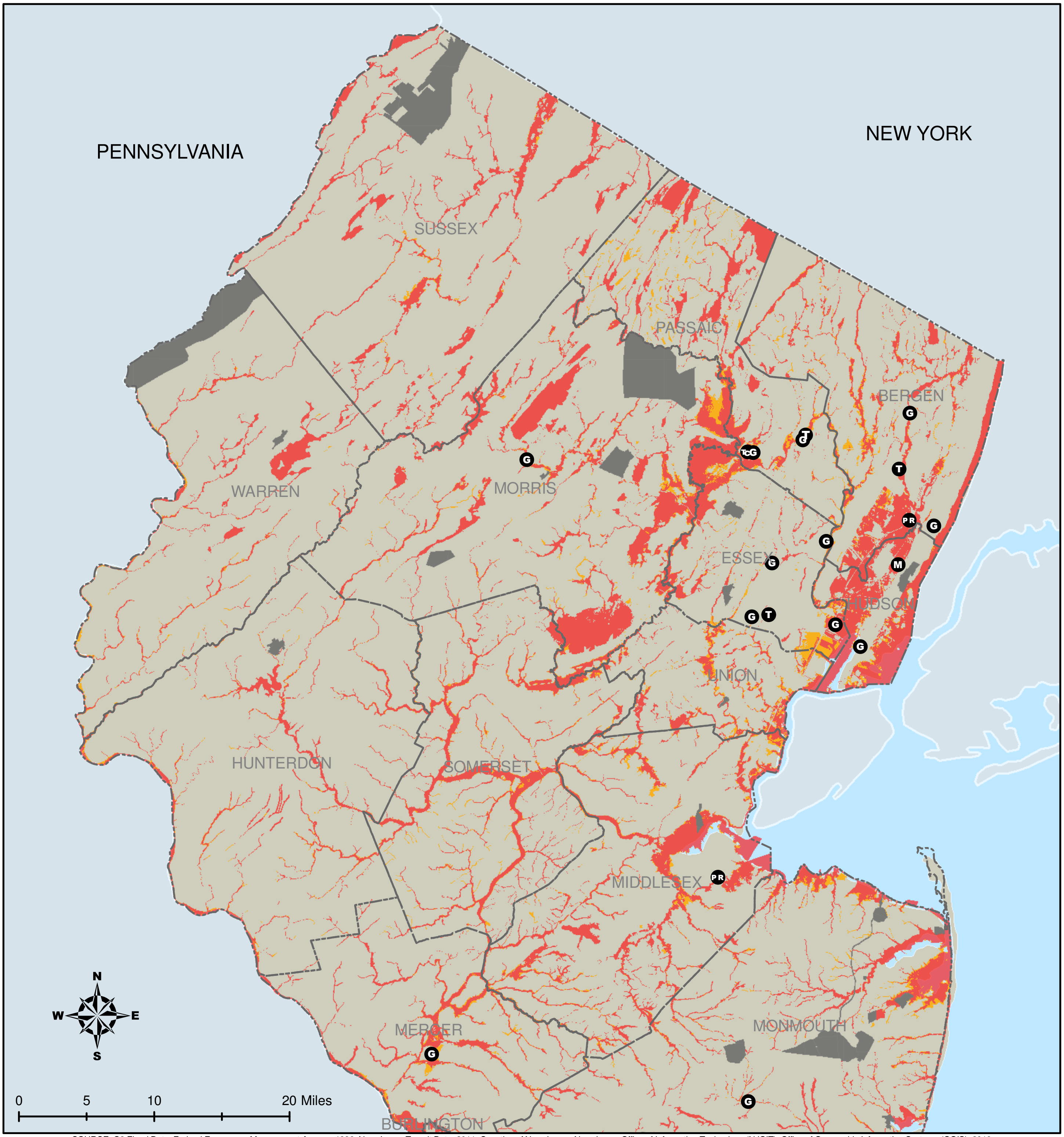
Structures include bridges, tunnels, culverts, retaining walls

ASSET CATEGORY	Climate Impact	Effect on Structures	Assets at Risk	Planning Horizon Timeframe (yrs)				Short-term Operational Impacts	Potential Asset Management Strategies	Implementation Cost Estimates per Unit		
				1 to 5	6 to 10	11 to 20	20-50			Low	High	
Structures	3. Storm Intensity and Frequency											
	3.1 Higher wind velocities	Increased pressure/forces on bridge stability	All Bridges	X	X	X	X	reduced and cancelled service	Evaluate adequacy of structures and implement remedies as required / increased maintenance	$250,000	$2,000,000	There would be increased maintenance for debris removal at the bridges and along the upstream fascias in the channels (which would also contribute to scour.)
	3.2 Increased rain frequency and rainfall per event	Inadequate culvert capacity	All Culverts	X	X	X	X		Install additional culverts	$10,000 each	$25,000 each	All current proposed supplemental or replacement culverts should be planned and designed to accommodate the anticipated future storm models with climate change effects in mind.
		Increased scouring of retaining walls, abutments, and foundations	All flood zone bridges and retaining walls	X	X	X	X	reduced and cancelled service	Increased maintenance and scour mitigation measures	$15,000 per mile	$2,000,000 per mile	Remedies may involve installing scour control to protect the substructures (rip rap, sheet piles, gabion walls, soil cement, articulating grout filled mattresses, etc.) as well as periodic debris removal and re-grading to prevent contraction scour due to potential shifts in the waterway channel.
	3.3 increased lightning	N/A	N/A					N/A				
	3.4 Increased snow levels per event	Impassable Bridges	All Bridges	X	X	X	X	cancelled or substitute service	Increased maintenance of snow removal	Additional Maintenance		An additional impact of increased snow levels is the effect that the melting snow will have with regards to heavier channel flow which would contribute to scour and debris build-up.
	3.5 more frequent icing events	Increase corrosion of bridges, tunnels and culverts due to road salt	All Bridges, Tunnels and Culverts	X	X	X	X	shortened maintenance schedule	Increased maintenance / cleaning and coating of structures / substructure concrete spall repairs	$180,000 each	$550,500 each	Blast (or spot) cleaning of superstructure (could be expensive depending on methods and containment requirements), miscellaneous steel repair or replacements (framing members, bolts / rivets, etc.), and paint coating. Increased substructure concrete spall repairs will also be necessary due to the road salt corrosive effect on the reinforcing steel. Non-Chloride based means of de-icing should be investigated and implemented. As an alternative to cleaning and coating, application of rust conversion treatment products (such as Stop Rust) to corroded areas may be considered.
	3.6 Increased flooding frequency and levels	Damage or destruction of structure	NJ coastal zone, Delaware Bay, and Tidal Delaware River structures	X	X	X	X	cancelled or substitute service	Evaluate adequacy of structures and implement remedies or replacement as required.	$250,000	$2,000,000	
		Increased scouring of retaining walls, abutments, and foundations	NJ coastal zone, Delaware Bay, and Tidal Delaware River retaining walls and bridges	X	X	X	X	reduced and cancelled service	Increased maintenance and scour mitigation measures	$180,000 each	$550,500 each	Remedies may involve installing scour control to protect the substructures (rip rap, sheet piles, gabion walls, soil cement, articulating grout filled mattresses, etc.) as well as periodic debris removal and re-grading to prevent contraction scour due to potential shifts in the waterway channel.

Appendix 2. Maps

New Jersey Transit Northern Jersey Bus Assets

Flood Hazard Areas



SOURCE: Q3 Flood Data, Federal Emergency Management Agency, 1996; New Jersey Transit Data, 2011; Counties of New Jersey ,New Jersey Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS), 2010.

Legend

- NJ County Boundary
- 1% Annual Chance of Flooding
- Between 0.2% and 1% Annual Chance of Flooding
- Area Not Included in Study

FIRST ENVIRONMENT

91 Fulton Street
Boonton, New Jersey 07005

Map 1

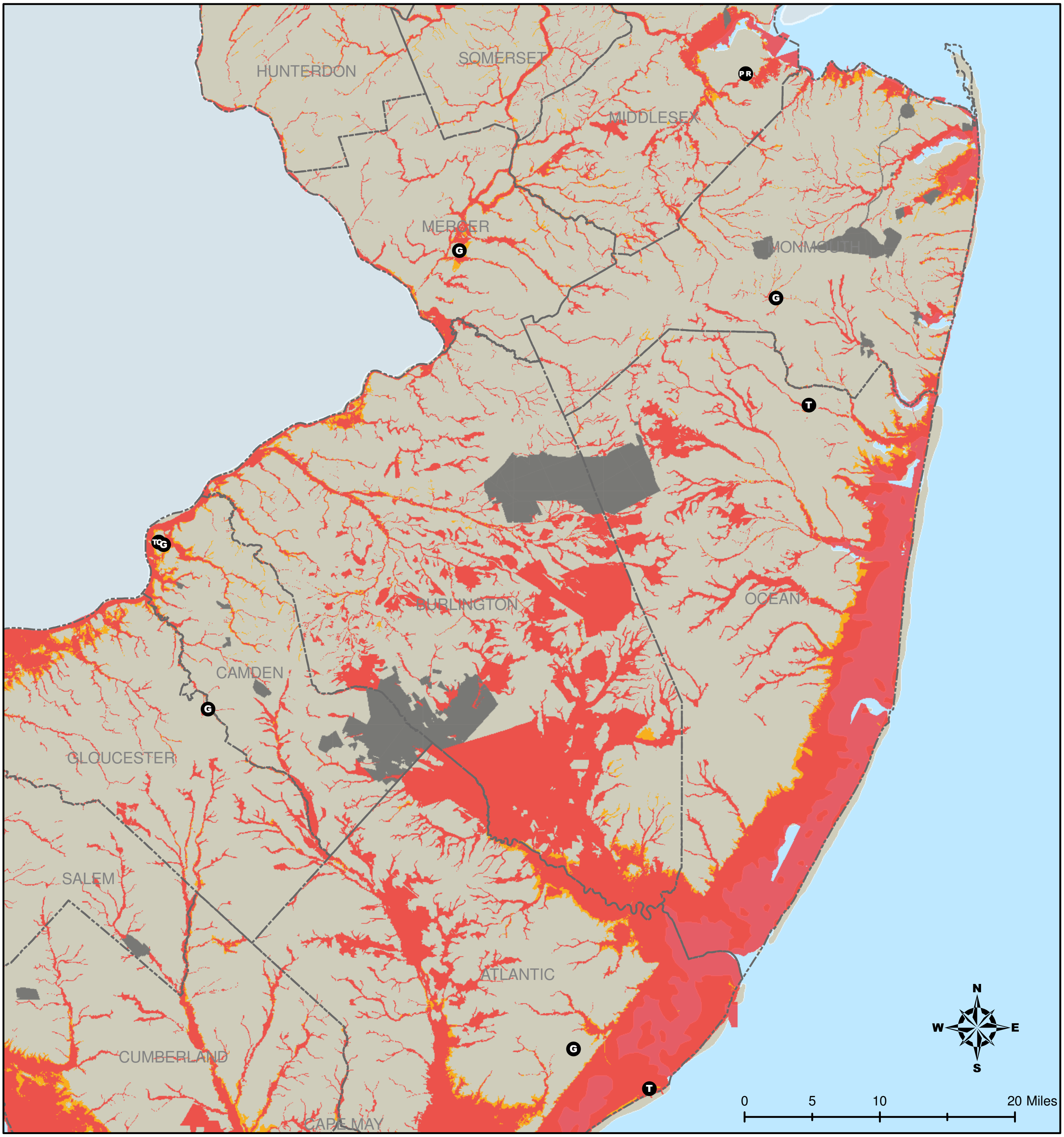
NEW JERSEY TRANSIT

IMPACTS: Flood Hazard Area Map
NJ Transit Northern Bus Assets

Designed	Drawn	Checked	Approved	Date
	CJM			03/15/12

New Jersey Transit Southern Jersey Bus Assets

Flood Hazard Areas



SOURCE: Q3 Flood Data, Federal Emergency Management Agency, 1996; New Jersey Transit Data, 2011; Counties of New Jersey ,New Jersey Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS), 2010.

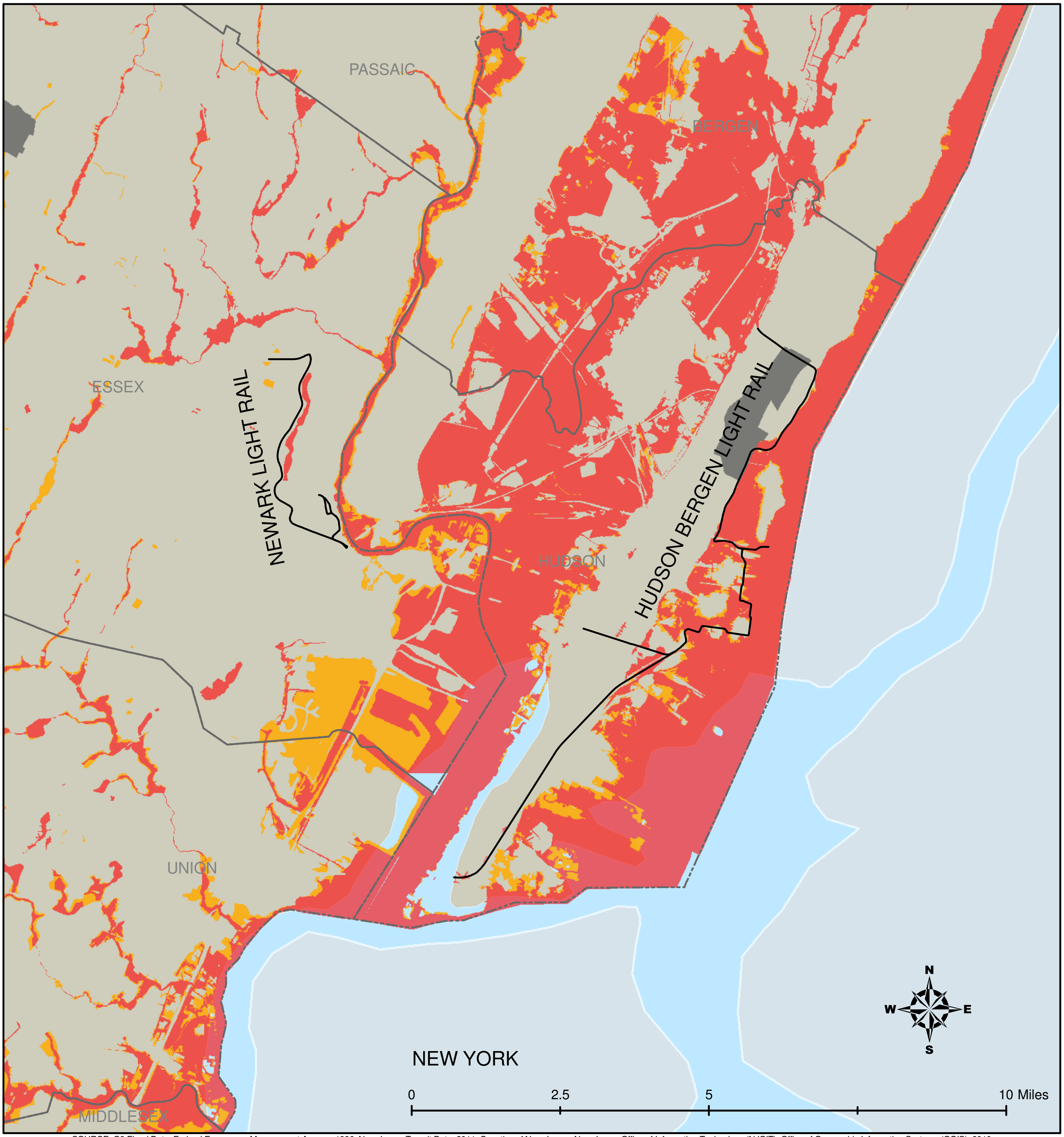
Legend

- NJ County Boundary
- 1% Annual Chance of Flooding
- Between 0.2% and 1% Annual Chance of Flooding
- Area Not Included in Study

FIRST ENVIRONMENT	MAP 2				
	NEW JERSEY TRANSIT IMPACTS: Flood Hazard Area Map NJ Transit Southern Bus Assets				
91 Fulton Street Boonton, New Jersey 07005	Designed	Drawn CJM	Checked	Approved	Date 03/15/12

New Jersey Transit Northern Jersey Light Rail Lines

Flood Hazard Areas



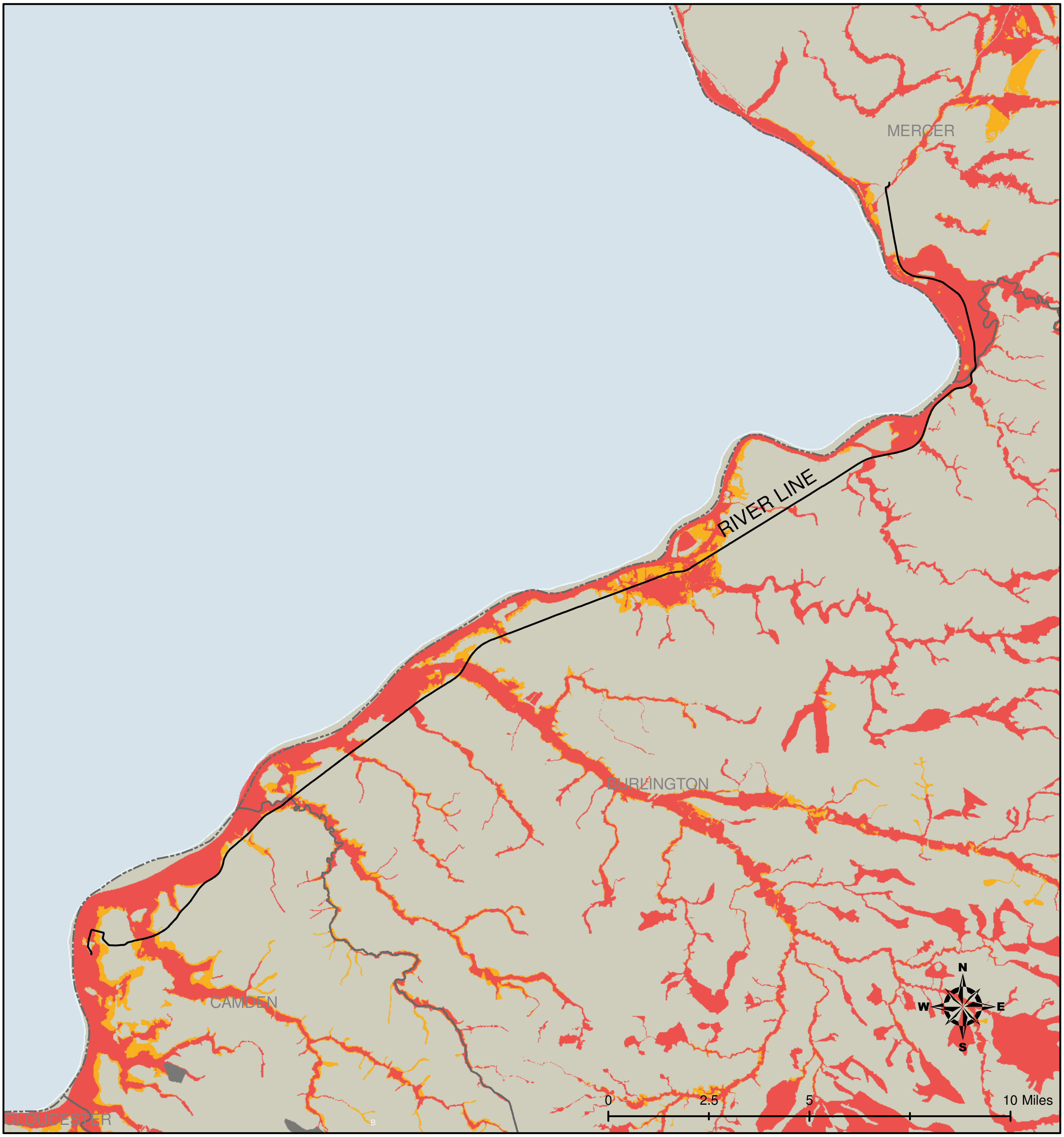
SOURCE: Q3 Flood Data, Federal Emergency Management Agency, 1996; New Jersey Transit Data, 2011; Counties of New Jersey ,New Jersey Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS), 2010.

Legend

- 1% Annual Chance of Flooding (100 Year Floodplain)
- Between 0.2% and 1% Annual Chance of Flooding (500 Year Floodplain)
- Area Not Included in Study
- Light Rail Line
- NJ County Boundary

FIRST ENVIRONMENT	MAP 3				
	NEW JERSEY TRANSIT IMPACTS: Flood Hazard Area Map NJ Transit Northern Jersey Light Rail Lines				
91 Fulton Street Boonton, New Jersey 07005	Designed	Drawn CJM	Checked	Approved	Date 03/15/12

New Jersey Transit Southern Jersey Light Rail Lines
Flood Hazard Areas



SOURCE: Q3 Flood Data, Federal Emergency Management Agency, 1996; New Jersey Transit Data, 2011; Counties of New Jersey ,New Jersey Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS), 2010.

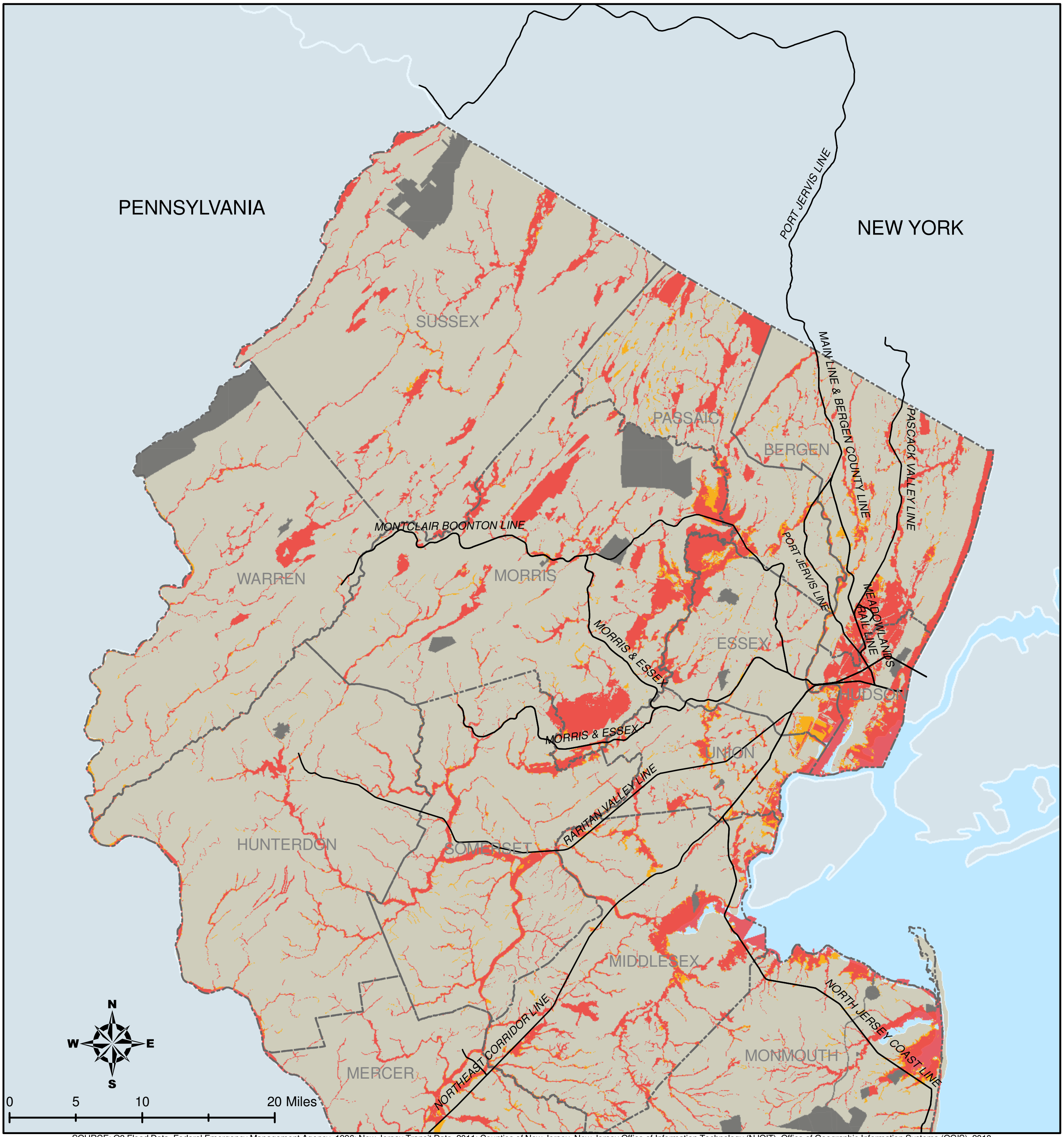
Legend

- 1% Annual Chance of Flooding (100 Year Floodplain)
- Between 0.2% and 1% Annual Chance of Flooding (500 Year Floodplain)
- Area Not Included in Study
- Light Rail Line
- NJ County Boundary

FIRST ENVIRONMENT	MAP 4				
	NEW JERSEY TRANSIT IMPACTS: Flood Hazard Area Map NJ Transit Southern Jersey Light Rail Lines				
91 Fulton Street Boonton, New Jersey 07005	Designed	Drawn CJM	Checked	Approved	Date 03/15/12

New Jersey Transit Northern Jersey Rail Lines

Flood Hazard Areas



SOURCE: Q3 Flood Data, Federal Emergency Management Agency, 1996; New Jersey Transit Data, 2011; Counties of New Jersey ,New Jersey Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS), 2010.

Legend

- 1% Annual Chance of Flooding (100 Year Floodplain)
- Between 0.2% and 1% Annual Chance of Flooding (500 Year Floodplain)
- Area Not Included in Study
- NJT Rail Line
- NJ County Boundary

FIRST ENVIRONMENT

91 Fulton Street
Boonton, New Jersey 07005

MAP 5

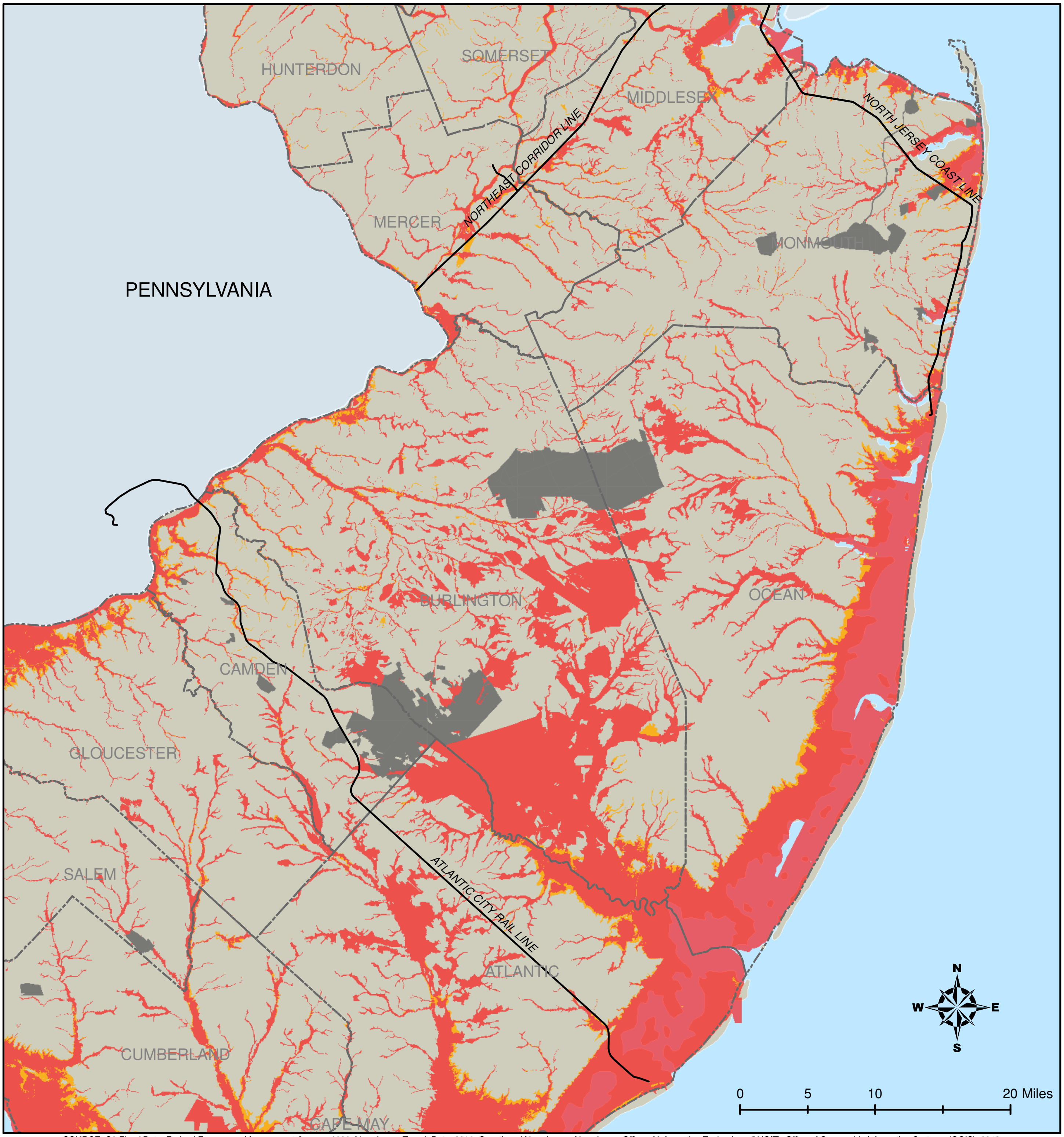
NEW JERSEY TRANSIT

IMPACTS: Flood Hazard Area Map
NJ Transit Northern Jersey Rail Lines

Designed	Drawn	Checked	Approved	Date
	CJM			03/15/12

New Jersey Transit Southern Jersey Rail Lines

Flood Hazard Areas



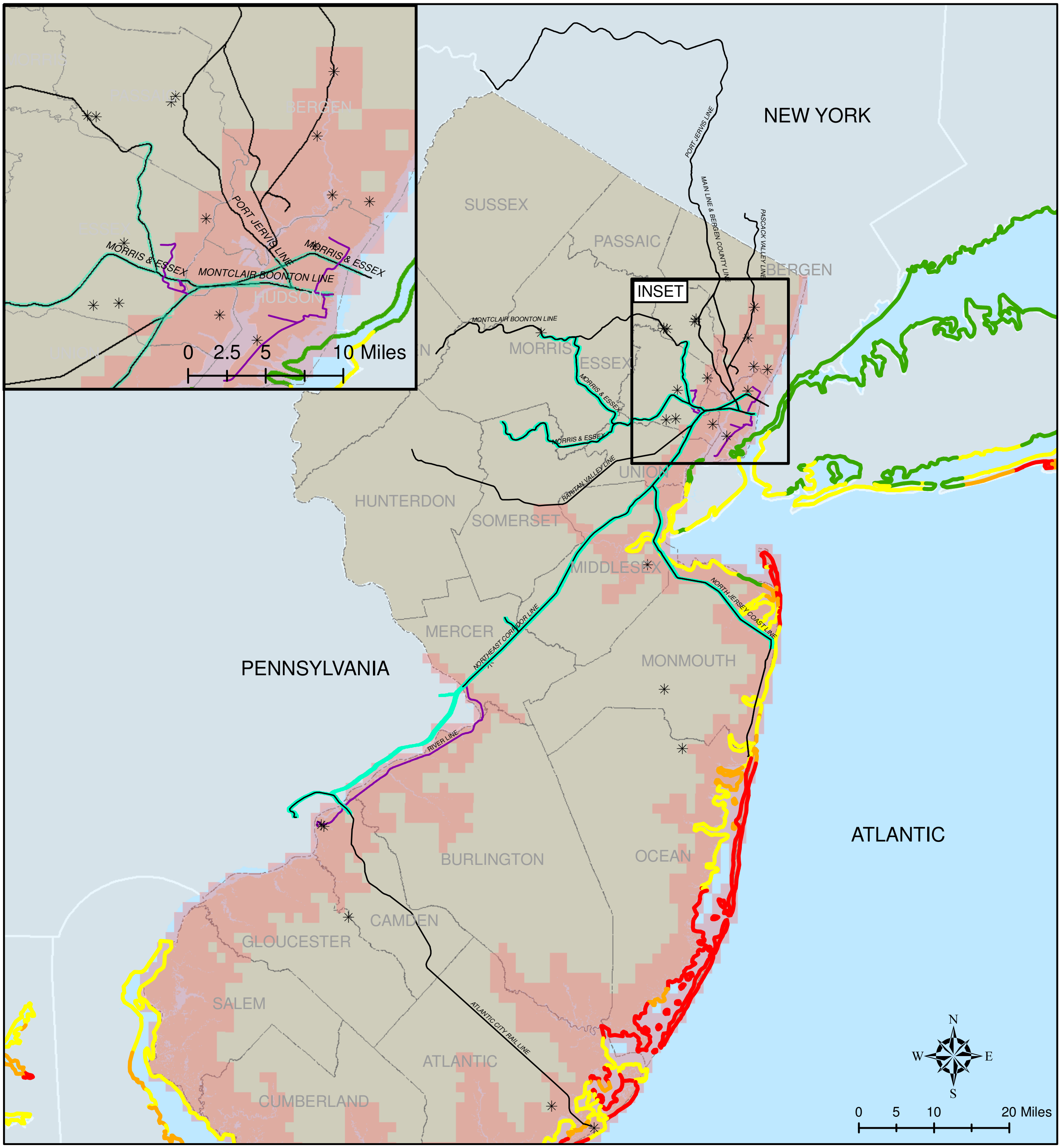
SOURCE: Q3 Flood Data, Federal Emergency Management Agency, 1996; New Jersey Transit Data, 2011; Counties of New Jersey ,New Jersey Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS), 2010.

Legend

- 1% Annual Chance of Flooding (100 Year Floodplain)
- Between 0.2% and 1% Annual Chance of Flooding (500 Year Floodplain)
- Area Not Included in Study
- NJT Rail Line
- NJ County Boundary

FIRST ENVIRONMENT	MAP 6
	NEW JERSEY TRANSIT IMPACTS: Flood Hazard Area Map NJ Transit Southern Jersey Rail Lines
91 Fulton Street Boonton, New Jersey 07005	Designed: / Drawn: CJM / Checked: / Approved: / Date: 03/15/12

New Jersey Transit Rail Lines
Coastal Vulnerability and Storm Surge Areas



SOURCE: NJDEP Tidelands ,New Jersey Department of Environmental Protection (NJDEP), Bureau of Tidelands Management, 1996; Coastal Vulnerability to Sea-Level Rise: A Preliminary Database for the U.S. Atlantic Coast, U.S. Geological Survey, 2001; New Jersey Transit Data, 2011; Counties of New Jersey ,New Jersey Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS), 2010.

Legend

Storm Surge Area*

Coastal Vulnerability Index*
- Low
- Moderate
- High
- Very High

Bus Asset (Terminals, Garages, Etc.)
NJT Rail Line
Light Rail Line
Catenary Line
NJ County Boundary

*Storm Surge (Tidelands) depict natural waterways now or formerly tide-flowed at mean high water at the time of mapping.

**The Coastal Vulnerability Index furnishes a broad overview of regions where physical changes are likely to occur due to sea-level rise based on a combination of variables including geomorphology, regional coastal slope, tide range, wave height, relative sea-level rise and shoreline erosion and accretion rates.

FIRST ENVIRONMENT
91 Fulton Street
Boonton, New Jersey 07005

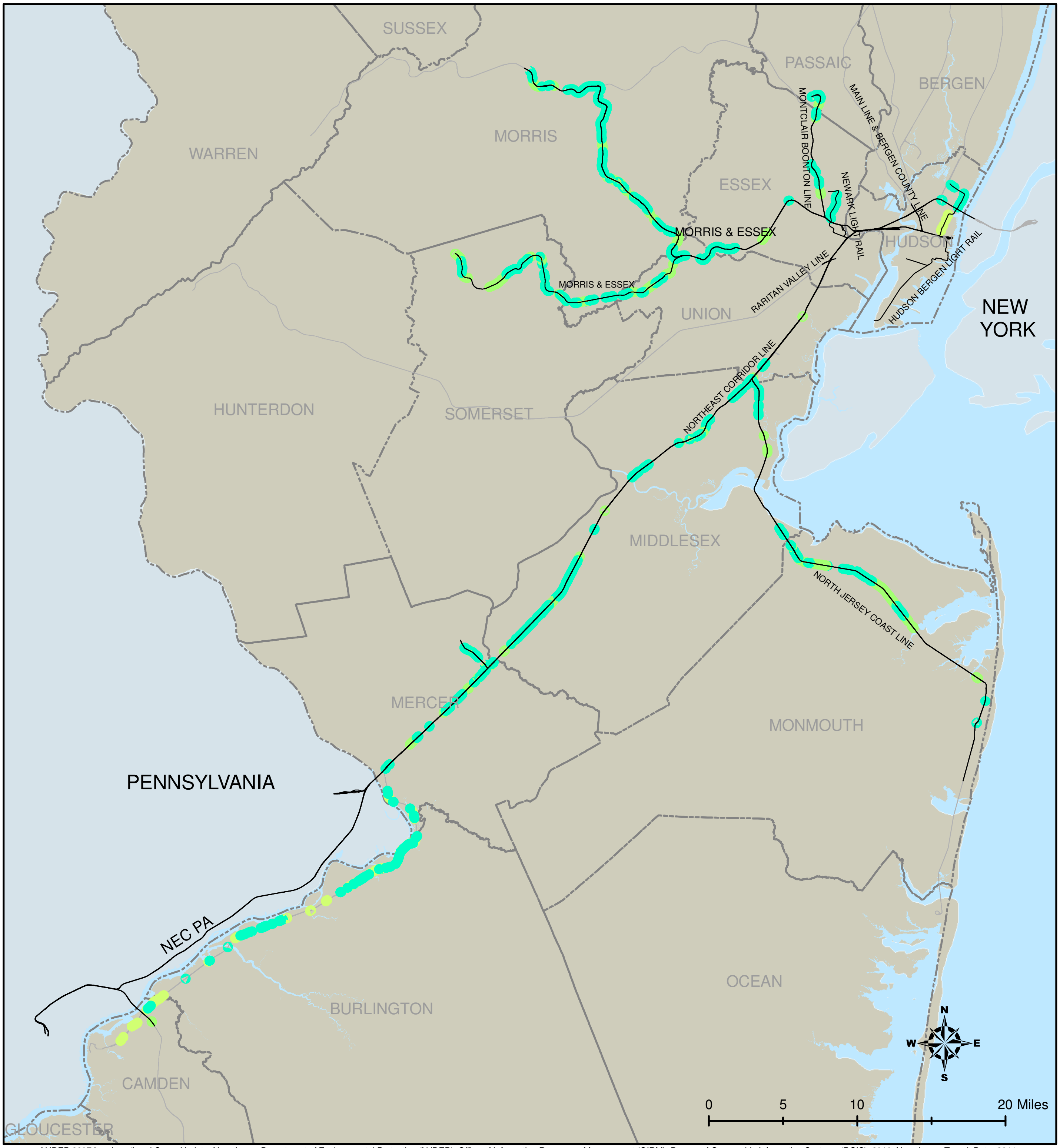
MAP 7

NEW JERSEY TRANSIT
IMPACTS: Coastal Vulnerability Index & Storm Surge Area Map
NJ Transit Rail Lines

Designed	Drawn	Checked	Approved	Date
	CJM			03/14/12

New Jersey Transit Catenary Rail Lines

Forested Areas



NJDEP 2007 Land use/Land Cover Update, New Jersey Department of Environmental Protection (NJDEP), Office of Information Resources Management (OIRM), Bureau of Geographic Information Systems (BGIS), 2010; New Jersey Transit Data, 2011; Counties of New Jersey, New Jersey Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS), 2010.

Legend

- Forested Area within 50' of Rail Line (Medium to High Density)
- Forested Area within 50' of Rail Line (Low to Medium Density)
- Catenary Rail Line
- NJ Rail Line
- NJ County Boundary

FIRST ENVIRONMENT	MAP 8				
	NEW JERSEY TRANSIT IMPACTS: Forested Area Map Rails with Catenary Poles/Lines				
91 Fulton Street Boonton, New Jersey 07005	Designed	Drawn CJM	Checked	Approved	Date 03/16/12

New Jersey Transit All Commuter Rail Lines
Forested Areas

NJDEP 2007 Land use/Land Cover Update, New Jersey Department of Environmental Protection (NJDEP), Office of Information Resources Management (OIRM), Bureau of Geographic Information Systems (BGIS), 2010; New Jersey Transit Data, 2011; Counties of New Jersey, New Jersey Office of Information Technology (NJOIT), Office of Geographic Information Systems (OGIS), 2010.

Legend

- Catenary Rail Line
- NJT Rail Line (Non-Catenary)
- Forested Area within 50' of Rail Line (Low to Medium Density)
- Forested Area within 50' of Rail Line (Medium to High Tree Density)
- NJ County Boundary

FIRST ENVIRONMENT	MAP 9				
	NEW JERSEY TRANSIT IMPACTS: Forested Area Map All Commuter Rail Lines				
91 Fulton Street Boonton, New Jersey 07005	Designed	Drawn	Checked	Approved	Date
		CJM			03/16/12